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Clean and sustainable energy policies in Turkey

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ABSTRACT

Energy is essential to life and human society cannot surviva without a continuous supply of energy. However, although energy has brought about significant changes in standards and life-styles, its generation, processing and consumption is also a source of both localized pollution and a major contributor to global climate change. In this context, at the international level, the challenges related to energy and climate change are at the very top of the agenda for action, and more than ever before, renewable energy is proving its potential as an important part of the solution. The rough their concrete contribution to clean and secure energy, renewables ensure that an increasing amount of energy is produced without using fossil fuels and without emitting greenhouse gases. Turkey is energy importing country, which 70% of total energy consumption supplied by imported energy. Turkey is also generously endowed with renewable energy sources. There is an estimated yearly renewable energy potential of around 560 TW h from commercially exploitable sources such as hydropower, wind, biomass, geothermal and solar energy. This study shows that Turkey has enough renewable energy potential to diminishes the country's energy dependency and greenhouse gases.

Contents

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1. Introduction

Energy is essential to economic and social development and improved quality of life in all countries. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially [1]. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption in the country [2]. Electricity supply infrastructures in many developing countries such as Turkey are being rapidly expanded as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth [3].

The warming of the global climate system as a result of increasing greenhouse gas (GHG) concentrations in the atmosphere has become a major concern worldwide [4]. Climate change is manifest in higher average global temperatures, rising global mean sea levels, melting ice caps and an increased intensity and frequency of extreme weather events [5]. Most scientific research suggests that the consequences of unabated climate change could be dramatic [6]. And while doubts remain about some of the concrete impacts, it seems clear that global warming will significantly increase the risk of a severe deterioration of the natural environment, with attendant effects on human wellbeing [7]. It is virtually impossible to reasonably quantify the impact of unabated climate change in economic terms, as this involves a very long time horizon and highly subjective judgments. But because of the large risks and uncertainties, and the potential for severe economic repercussions, strong and early action to mitigate climate change is advocated [8]. Looking at long-term climate change mitigation from this risk-management perspective is not primarily an economic issue but an ethical imperative [9–12].

There is a growing concern that sustainable development may be compromised unless measures are taken to achieve balance between economic, environmental and social outcomes [13]. Since the early 1980s, Turkish energy policy has concentrated on market liberalization in an effort to stimulate investment in response to increasing internal energy demand. This paper provides an overview of clean and sustainable energy policies in Turkey [14–17].

2. Global energy consumption

2.1. Coal

Coal was the first fossil fuel to be used on an industrial scale, and it remains a major force in world energy and has indeed been the fastestgrowing worldwide in recent years. After centuries of mineral exploration, the location, size and characteristics of coal resources are well-established. Economically recoverable reserves are reported to exist in some 75 countries and the global total amount of coal at end-2008 of 860 billion tons was 1.6% higher than at end-2008. Table 1 shows world primary energy consumption [18,19].

Of the total world coal reserves, 405 billion (47%) is classified as bituminous coal (including anthracite), 260 billion (30%) as subbituminous and 195 billion (23%) as lignite. The countries with the largest recorded coal reserves are unchanged from recent editions of the SER: the USA, the Russian Federation and China continue to lead the way, with nearly 60% of global reserves between them, while Australia and India are also in the top rank [20].

Around 5.8 billion tons of hard coal and 953 million tons of brown coal were used worldwide in 2008 [19]. Since 2000, global coal consumption has grown faster than any other fuels. The five largest coal users such as China, USA, India, Japan and Russia account for around 72% of total global coal use [18]. On the other hand, the use of coal is expected to rise by over 60% by 2030, with developing countries accounting for around 97% of this increase. China and India alone will contribute 85% of the increase for demand in coal over this period. Most of this demand is in the power generation sector, where coal's share in global electricity generation is set to increase from 41% today to 44% by 2030 [1,2,18,19].

2.2. Oil

Proved reserves of oil, as assessed for the SER, continue to show a substantial supply base for the short-medium term [20]. The global level of proved recoverable reserves, based on information from World Energy Council Member Committees and supplementary sources, stood at 1239 billion barrels (163 billion tons) at end-2008, some 24 billion barrels (3 billion tons) higher than at the end-2005 level [20]. On the other hand, the Middle East remains the principal location of oil reserves, with 61% of the global total, followed by Africa with 11%, South America 10%, and Europe (including the whole of the Russian Federation) 8%, followed by Asia and North America each at around 5% [2,8,20].

2.3. Natural gas

At the present level of 185.5 trillion cubic meter (tcm), global gas reserves are equivalent to more than 54 years' production at the 2008 rate. The countries with the largest natural gas reserves are still the Russian Federation, the Islamic Republic of Iran and Qatar, but Turkmenistan has now overtaken Saudi Arabia to take fourth place in the global ranking list. At end-2008, the Middle East accounted for 41% of the world's gas reserves, Europe (including the whole of the Russian Federation) for 27% and Asia for 15% [2,8,20].

Primary energy demand is expected to increase at an average annual growth rate of 1.4% from 2010 and 2030 [8,19]. The share of natural gas will rise from 21% at the present time to 23% in 2030. The relative gas market share varies at the regional level. The share of gas in primary energy demand is expected to grow significantly in Europe, Africa, the Middle East and Asia. Natural gas demand is projected to grow by 1.6% per year between 2007 and 2030 to a total of 4.4 tcm [8,20]. Total natural gas production in North America will increase from 722 bcm in 2005 to 900 bcm in 2030. Unconventional production increases from 244 bcm in 2006 to 374 bcm in 2030 [2,8,19,20].

2.4. Nuclear

There were 437 nuclear power reactors in operation at the beginning of 2010, with an aggregate generating capacity of 370 GW_e. Eleven construction starts were made in 2009, ten of them in Asia. A number of countries uprated existing plants by up to 20%, a highly effective way of bringing new capacity on-line [8,20].

In 2009, the US Nuclear Regulatory Commission approved eight licence renewals of 20 years each, bringing the number of approved renewals to 59 [8]. Licence renewals were either granted or being processed in several other countries. Between 2007 and 2009 construction started on 29 nuclear power plants representing 29.1 GW_e of new installed capacity, bringing the total number under construction to 55 reactors at the end of 2009, the largest number since 1992. The post-2000 trend of licence renewals or extensions for many operating reactors continued, especially in the USA [8,20,21].

During the first decade of the new millennium, annual electricity production from the global fleet of nuclear power plants ranged between 2544 TW h and 2661 TW h. The 2009 production of 2 568 TW h translates into a market share of 14%, i.e., every seventh kilowatt-hour produced in the world was generated by nuclear power [21]. On the other hand, the 55 reactors under construction are in Asia (including the Middle East), as were 30 of the last 41 new reactors to have been connected to the grid. China's target is 40 GW_e of nuclear power capacity in 2020, compared to 8.4 GW_e today [8,20].

2.5. Hydropower

Hydro-electric power is currently the largest of the perpetual or so-called Renewable energy resources [22]. Hydro contributes to electricity generation in 160 countries and the least-cost way to increase hydro generating capacity is almost always to modernise and expand existing plants [8]. Most of the hydro plant presently in operation will require modernisation by 2030. While capacity expansions are generally made at existing hydro stations, there are sometimes opportunities for installing generators at nonhydro dams. There are 45,000 large dams in the world and the majority do not possess a hydro component [2,8,20].

There is considerable debate regarding the quantification and classification of the world's hydropower resources [20]. Worldwide technical potential, estimated by the World Atlas at 14,604 GW h/yr, is increasingly challenged as it tends to be based only on specific sites that have been studied at some point in the distant past. It thus tends to exclude other sites that could be developed [8]. Economically feasible potential, estimated by the World Atlas at 8771 GW h/yr, is also questioned on the basis that much of the evaluation is based on energy prices at different times in the past, again tending to miscalculations [18–20].

Most hydropower projects were developed to provide base load to the power system, and this pattern will continue in developing countries. Currently, there are more than 127 GW of pumped storage throughout the world. Recent reporting in the technical press indicates that at least 15 projects are under construction in nine countries, and that these will add a further 8.8 GW of capacity. The power plants range in size from 150 to 1353 MW. It is anticipated that the market for pumped storage will increase by 60% over the next four years [2,8].

2.6. Bioenergy

At present, forestry, agricultural and municipal residues, and wastes are the main feedstocks for the generation of electricity and heat from biomass [23,24]. In addition, very small shares of sugar, grain, and vegetable oil crops are used as feedstocks for the production of liquid biofuels. Today, biomass supplies some 50 EJ globally, which represents about 10% of global annual primary energy consumption [8]. This is mostly traditional biomass used for cooking and heating. There is significant potential to expand biomass use by tapping the large volumes of unused residues and wastes. Based on this diverse range of feedstocks, the technical potential for biomass is about 1300 EJ/yr by 2030, although most biomass supply scenarios that take into account sustainability constraints indicate an annual potential of between 200 and 500 EJ [8,20].

Fuelwood consumers are of two very different types: in industrialised countries, the presentday wood user is likely to use a highly-efficient combustion appliance under strict regulations regarding emissions, whereas the typical developing-world consumer uses small, inefficient and highly-polluting fires and stoves. Indoor air pollution is a major health problem in less-developed countries [8,17–20].

Another large secondary transformation of biomass is electricity generation. CHP plants have been operated by biomass-processing industries such as sugar, wood products and chemical pulping for many years, with some producing a surplus which is exported to national or regional networks. In more recent times, they have been joined by biomass-fired CHP linked to district heating. Co-firing biomass with coal has also been successfully introduced in some locations [8,20,23–25].

2.7. Solar energy

The annual solar radiation reaching the earth is over 7500 times the world's annual primary energy consumption of 450 exajoules; it varies from place to place, with some parts of the earth receiving a much greater irradiance than the average annual level of 170 W/m^2. However, there is a useable solar resource in virtually all parts of the world, and economically attractive applications are not confined to the sunniest regions [26–28].

Adoption of solar water heating can have a great impact on the reduction of peak electrical load and thus greenhouse gas emissions [28]. For example, if all the electric water heaters in the USA were replaced by solar water heaters, it would reduce the peak load by about 100 GW. Solar technologies can make a substantial contribution to the energy budget of modern buildings, and consequently to the world's energy use [8]. Buildings can be the largest collectors of solar energy and therefore the electrical appliances with innovative energy efficient models, can reduce electricity demand and increase the significance of, e.g. photovoltaic electricity, to the whole energy budget [8,20].

PV panels are solid-state and are therefore very rugged, with a long life. Currently, the commonest panels are based on crystalline and polycrystalline silicon solar cells [26]. Their efficiency has gradually increased, while costs have declined [27]. A major advantage of PV devices is that they can be installed as stand-alone systems, providing power ranging from microwatts to megawatts. In 2009, sales of PV modules for terrestrial applications exceeded 7 2001 700 MWp. The global market has been is growing at a phenomenal rate: an average of 47% per annum over the past five years [18–20].

2.8. Geothermal energy

Geothermal utilisation is commonly divided into two categories: electricity generation and direct use [22]. Geothermal electricity are mostly major world economies, the six countries with the highest percentage share of geothermal in their power production are all relatively small, with three out of the top six being located in Central America, a part of the world rich in high-temperature geothermal resources [20,28].

Direct use of the geothermal energy encompasses a multitude of different applications. Overall, ground-source heat pumps account for nearly one-third of recorded direct geothermal utilisation [29]. This application is based upon the use of normal ground or ground-water temperatures, which are relatively constant and are available everywhere. The total installed capacity of geothermal heat pumps grew at an annual rate of nearly 21% over the ten years and the most installations have been in North America and Europe, although other parts of the world (e.g. China) are beginning to develop significant heatpump capacity in 2009 [8].

The principal other uses of (generally relatively low-temperature) geothermal heat are bathing and swimming, space heating, and horticultural/aquacultural/agricultural applications. The prominence of bathing/swimming reflects the large number of hot springs found throughout the world, particularly in Japan [20]. Geothermally-based space heating has been developed to a high degree in Iceland, where its market penetration has reached around 90%. Geothermal power is generated by using steam or a

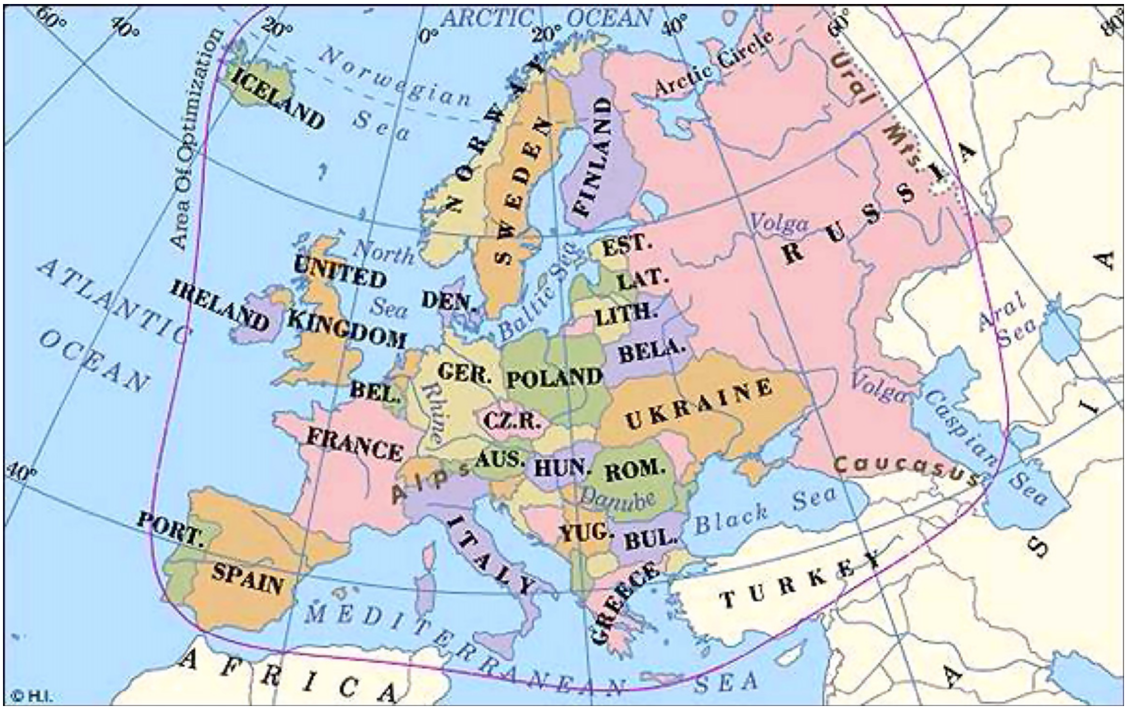

Fig. 1. Turkey's location between Europe and Asia.

hydrocarbon vapour to turn a turbine-generator set to produce electricity. A vapour-dominated (dry steam) resource can be used directly, whereas a hotwater resource needs to be flashed by reducing the pressure to produce steam, normally in the 15–20% range [20,28,29].

In 2008, approximately 10,700 MW_e of geothermal electricity generating capacity was installed, producing over 63,000 GW h/yr [18]. Installed capacity for direct heat utilisation amounted to about 50,000 MWt, with an annual output of around 430,000 TJ (equivalent to about 120,000 GW h). The annual growth in energy output over the past five years has been 3.8% for electricity production and around 10% for direct use (including geothermal heat pumps). Energy produced by ground-source heat pumps alone has increased by 20% per annum over the same period. The low growth rate for electric power generation is primarily due to the low price for natural gas, the main competitor [8,20].

2.9. Wind energy

Wind energy has been utilised by man for thousands of years, initially to provide mechanical energy and now to provide electricity [22]. It is available virtually everywhere on earth, although there are wide variations in wind strengths. If only 1% of the area was utilised, and allowance made for the lower load factors of wind plant (15–40%, compared with 75–85% for thermal plant) that would still correspond, roughly, to the total worldwide capacity of all electricity-generating plant [30].

World wind energy capacity has been doubling about every three and a half years since 1990 as is doubtful whether any other energy technology is growing, or has grown, at such a rate. Total capacity at the end of 2008 was over 120 GW and annual electricity generation around 227 TW h, roughly equal to Australia's annual consumption. The United States, with about 25 GW, has the highest capacity but Denmark with over 3 GW, has the highest level per capita, and production there corresponds to about 20% of Danish electricity consumption [8]. Several commercial types of wind turbine now have ratings over 3 MW and diameters around 60–80 m; machines for the offshore market have outputs up to 6 MW and diameters up to 126 m. Machine sizes have increased for two reasons [20].

3. Energy sources in Turkey

3.1. Geographical characteristics of Turkey

Turkey is one of the largest countries in Europe and Middle East with its 779452 km^2 total area (23764 km^2 on the European side, 755688 km^2 on the Asian side) [31]. The country lies between 36 and 42 north latitude and 26–45 east longitude (roughly rectangular in shape) and situated between two continents – Europe and Asia (Fig. 1). It is surrounded by three seas with a total of 8372 km total coastline; the Aegean with 2805 km, the Mediterranean with 1577 km, the Black Sea with 1695 km and the inner sea Marmara with 972 km. The Marmara connects the Black Sea and the Aegean via two straits: Istanbul and Canakkale straits. The country has seven geographical regions: Marmara, Aegean, Mediterranean, Southeast Anatolia, East Anatolia, Black Sea and Central Anatolia. The neighboring countries are Greece and Bulgaria to the northwest, Armenia and Georgia to the northeast, Iraq and Iran to the southeast and Syria to the south (Fig. 2). The highest mountain in Turkey is Mount Ararat (5165 m) and biggest lake is Lake Van: both are located in eastern Anatolia [31–33].

3.2. Energy sources and problems in Turkey

As a developing country an in conjunction with its fast growing economy and population Turkey's energy consumption has increased rapidly between 1990 and 2007. While total primary energy consumption in 1990 was 50.47 million tons of oil equivalent (Mtoe), in 2007 it raised 107.78 Mtoe. On the other hand, total energy production in 1990 was 27.39 and 28.57 in 2007 (Tables 1, 2 and Fig. 3) [33–35].

As it can be seen from Fig. 3, Turkey is an energy importing country and dependent on the imported energy sources. Furthermore

Fig. 2. The map of Turkey.

Table 1
World primary energy consumption by fuel (Mtoe).

	1980	2000	2007	2020
Coal	1788	2295	3253	4908
Oil	3107	3649	4129	5109
Gas	1235	2088	2407	3670
Nuclear	186	675	728	901
Hydropower	148	225	268	414
Biomass and waste	748	1045	1188	1662
Other renewables	12	55	76	350
Total	7223	10,034	12,049	17,014

Mtoe: Million tons of oil equivalent.

Table 2
Total energy production in Turkey (Mtoe).

Energy Sources	2007	2010	2020
Coal and lignite	14.50	26.15	32.36
Oil	2.48	1.13	0.49
Gas	0.94	0.17	0.14
Nuclear	–	–	7.30
Hydropower	3.86	5.34	10.00
Geothermal	0.70	0.98	1.71
Wood and Biomass	5.27	5.12	4.96
Solar/wind/other	0.42	1.05	2.27
Total production	28.17	39.94	59.23

this trend seems to be continuing in the future. Although it has a wide variety of energy sources, the quality and quantity of most of the sources are not sufficient to produce energy. Some of the energy sources in Turkey are hard coal, lignite, asphalt, oil, natural gas, hydropower, geothermal, wood, animal and plant wastes (bio mass), solar and wind energy [36–40]. The proven reserves of lignite, the most abundant domestic energy source, is 7300 million ton and found in almost all of the country's regions. Coal and lignite has the largest percentage in total energy production with its 51.5% share. After lignite, wood has the greatest share in total energy production with its 18.7% and oil accounts for 8.8%, 13.7% hydro and the final 7.3% includes animal wastes, solar, gas, geothermal electricity and geothermal heat [41–45] (Tables 3 and 4).

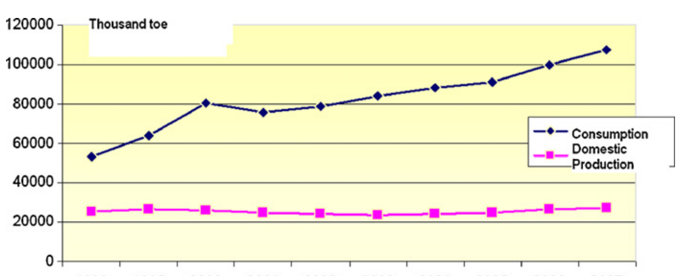

Fig. 3. Primary energy production and consumption in Turkey.

Table 3
Total energy consumption in Turkey (Mtoe).

Energy Sources	2007	2010	2020
Coal and lignite	36.46	39.70	107.57
Oil	35.60	51.17	71.89
Gas	26.40	49.58	74.51
Nuclear	–	–	7.60
Hydropower	3.86	5.34	10.00
Geothermal	0.70	0.97	1.71
Wood and Biomass	5.27	5.12	4.96
Solar/wind/other	0.44	1.05	2.27
Total consumption	107.61	152.93	280.51

Turkey's various renewable energy sources represent its second largest energy source after coal [32–35]. Biomass and animal waste account 67.3%, hydropower 29.5%, geothermal 2% and wind and solar account for 1.2% each of total renewable energy production [46–50]. There are many rivers in Turkey, thus water sources are one of the most important energy sources. 18.5% of electricity generation was provided by hydropower in 2007, and it increased to 26% in 2020. Turkey's largest hydroelectric power plant is the Atatürk Power Plant, which has the 6th largest capacity in the

Table 4
Yearly renewable energy potential in Turkey.

Renewable energy	Technical	Economical
Solar electric (billion kW h)	6105	305
Solar thermal (Mtoe)	500	25
Hydroelectric (billion kW h)	240	130
Wind electric (billion kW h)	120	60
Geothermal electric (billion kW h)	2	1
Geothermal heat (Mtoe)	7500	2850
Classic biomass (Mtoe)	10	8
Modern biomass (Mtoe)	40	25

Table 5
Turkey's air pollutant emissions in 2006 by source x (1000 tons).

	SO_2	NOx	VOC	CO
Power stations	1288.7	186.4	7.2	24.1
Industrial combustion	512.8	207.3	3.3	76.0
Non-industrial combustion	76.5	208.6	176.5	1464.5
Industrial processes	48.2	17.6	48.0	6.5
Mobile sources	22.0	454.0	123.7	1474.2
Miscellaneous	–	12.2	36.2	561.2

world, with the capacity of 2400 MW_e Karakaya with 1800 MW_e and Keban 1330 MW_e. Thirty four hydro plants are under construction, and 329 more hydro power plants are projected [37–41]. The largest hydro power project in Turkey is the Southeastern Anatolia Project (GAP), which covers 74,000 km^2 of the country. Upon competition, GAP will have an installed capacity of 7476 MW 22% of Turkey's total estimated economic potential [37,38].

Along with the economic growth and population increase, significant increases were observed both in primary energy and electricity consumption between 1975 and 2008 (see Fig. 4). Consumption of primary energy reached 107.8 Mtoe as of the end of 2007 with an annual average increase of 2.9% while electricity consumption reached 169.3 billion kW h with an annual average increase of 4.6% during this period [33,34]. These increases are more evident in the period following 2003, since the impact of the 2001 economic crisis was alleviated, and the economy stabilized. During this term, primary energy and electricity utilisation grew at an annual average rate of 5.4% and 6.3%, respectively [35,36]. Fig. 5 shows electricity consumption by source in Turkey [34].

4. Renewables in Turkey

Renewable energy supply in Turkey is dominated by hydropower and biomass [51,52], but environmental and scarcity-of-supply concerns have led to a decline in biomass use, mainly for residential heating. Total renewable energy supply declined from 1990 to 2007, due to a decrease in biomass supply [59,60]. As a result, the composition of renewable energy supply has changed and wind power is beginning to claim market share. As a contributor of air pollution and deforestation, the share of biomass in the renewable energy share is expected to decrease with the expansion of other renewable energy sources. Table 5 shows yearly renewable energy potential in Turkey [51–58].

Total gross hydropower potential and total energy production capacity of Turkey are nearly 60 GW and 120 TW h/yr, respectively and about 30% of the total gross potential may be economically exploitable. At present, only about 35% of the total hydroelectric power potential is in operation [61–66]. The national development plan aims to harvest all of the hydroelectric potential by 2020. The contribution of small hydroelectric plants to total electricity generation is estimated to be 6–8% [64,65]. On the other hand, the GAP is one of the largest power generating, irrigation, and development projects of its kind in the world, covering 3.0 million ha of agricultural land [40,41]. This is over 10% of the cultivable land in Turkey; the land to be irrigated is more than half of the presently irrigated are in Turkey. The GAP project on the Euphrates and Tıgris Rivers encompasses 22 dams and 19 hydroelectric power plants. Once completed, 27 billion kW h of electricity will be generated and irrigating 1.7 million hectares [37,40,41,64,65].

Biomass is the major source of energy in rural Turkey [66–70]. Biomass potential includes wood, animal and plant wastes. Among the biomass energy sources, fuelwood seems to be the most interesting because its share of the total energy production of Turkey is high at 21%. The total biomass energy potential of Turkey is about 32 Mtoe [52,53]. The amount of usable biomass potential of Turkey is approximately 17 Mtoe. The electrical production from usable biomass has a net impact of 4.4 billion USD in personal and corporate income and represents more than 160,000 jobs. There is a total 4 million ha of degraded coppice forests for energy forestry applications in Turkey. The improvement of degraded coppice forests is a very important activity, as important as forestation. Converting coppice forests into productive energy forests in order to meet continually-increasing fuel requirements in Turkey prevents the destruction of highly productive forests, thereby supplying more wood raw material for the forest industry, which at present operates with a low capacity. At the end of 2007, 643,247 ha of energy forest have been established [34–36].

Biogas systems are considered to be strong alternatives to the traditional stoves in rural Turkey [52]. The economic of biogas systems are compared with traditional heating systems fuelled by wood, coal and wood mixture, and dried animal waste in three different climatic regions in the country [51–53]. The technical data used in the analysis are based on the experimental results. Seven different comparisons are made between the biogas and traditional systems. The payback periods, cumulated life-cycle savings and the cost of biogas are calculated for a wide range using two unstable economic parameters, discount and inflation rates. The quality of the model and the assumptions are discussed. The results provide evidence of the economic viability of biogas systems over the traditional space heating systems of rural Turkey in many instances [33–35].

Turkey is one of the countries with significant potential in geothermal energy (at present seventh in the world) and there may exist about 2000 MW_e of geothermal energy usable for electrical power generation. Turkey's total geothermal heating capacity is about 31,500 MW_{th}. At present, heating capacity in the country runs at 1240 MW_{th} equivalent to 150,000 households. These numbers can be heightened some seven-fold to 7180 MW_{th} equal to 610,000 households through a proven and exhaustible potential in 2010. Turkey must target 1.1 million house holds equivalent 8900 MW_{th} in 2020 [34,35,44,45].

The yearly average solar radiation is 3.6 kW h/m^2-day and the total yearly radiation period is approximately 2640 h, which is sufficient to provide adequate energy for solar thermal applications. In spite of this high potential, solar energy is not now widely used, except for flat-plate solar collectors. They are only used for domestic hot water production, mostly in the sunny coastal regions [31–35]. In 2007, country has about total 7.8 million m^2 solar collectors and it is predicted that total energy production is about 0.440 Mtoe in 2007. Although solar energy is the most important renewable energy source it has not yet become widely commercial even in nations with high solar potential such as Turkey [46,48]. The energy consumption for heating and cooling of buildings in Turkey was about 25 Mtoe for the year 2007 [31,35,50]. The average household in Turkey needs more that 60% of its total energy consumption for space heating. The cooling demand in buildings increased rapidly in south region of the country at the summer season. The reason, beside general climatic and architectural boundary conditions, is an increase in the internal cooling load and higher comfort requirements. These aspects show the huge potential in this field for the implementation of advanced thermal energy storage technologies in Turkey [31–35].

There are a number of cities in Turkey with relatively high wind speeds. These have been classified into six wind regions, with a low of about 3.5 m/s and a high of 5 m/s at 10 m altitude, corresponding to a theoretical power production between 1000 and 3000 kW h/(m^2 yr). The most attractive sites are the Marmara Sea region, Mediterranean Coast, Agean Sea Coast, and the Anatolia inland. Capacity is likely to grow rapidly, as plans have been submitted for just under a further 600 MW of independent facilities. At start 2009, total installed wind energy capacity of Turkey is only 800 MW [49,50,71–79].

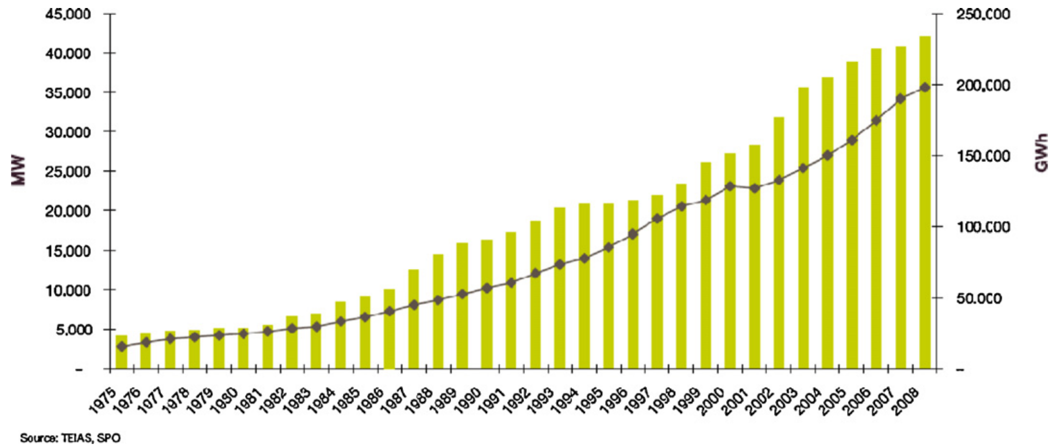

Fig. 4. The total power and gross electricity consumption in Turkey.

5. Air pollution in Turkey

Greenhouse gas emissions from fuel combustion jumped 65% in the 1990s. In recent years, Turkey's energy consumption increasing very fastly due to its economical development. The Turkish government is now in the process of developing a strategy to reduce the growth of greenhouse gases. Turkey will have the obligation to implement measures and polices to mitigate greenhouse gas emissions but will not be required to meet a specific greenhouse gas emission target [31–33].

Turkey has achieved decoupling of SOx, NOx and CO emissions from economic growth. In 2006, estimated SO_2 emissions are 1.94 million tons, while GDP and fuel consumption increased by 26 and 23% respectively. Major contributors to SOx emissions continue to be power plants (66.3%) and industrial combustion (26.1%) [80–82]. On the other hand, NOx emissions, estimated at 1.2 million tons in 2006 [31,32]. The major contributor to NOx emissions continued to be mobile sources. Power stations and industrial combustion accounted for 16.9 and 18.8% respectively (Table 5) [35,36,80–82].

Carbon monoxide emissions amounted to 3.6 million tons in 2006 and mostly come from non-industrial (41%) and mobile (41%) sources (Table 6). On the other hand, volatile organic compound (VOC) emissions have increased slightly. Total emissions were estimated at 554 400 tons in 2004, with nonindustrial fixed sources contributing 31.5%, mobile sources 22.7% and solvents 28.4% of total VOC emissions [80–82].

Table 6
Greenhouse gas emissions by gas (million tons CO_2 eq).

Years	CO_2	CH_4	N_2O	Total
1990	139.6	29.2	1.3	170.1
1992	152.9	36.7	4.0	193.6
1994	159.1	39.2	2.2	200.5
1996	190.7	45.0	6.1	242.1
1998	202.7	47.7	5.6	256.6
2000	223.8	49.3	5.8	280.0
2002	216.4	46.9	5.4	270.6
2003	231.0	47.8	5.3	286.3
2004	241.9	46.3	5.5	296.6
2006	256.1	49.4	3.4	312.2

Between 1990 and 2006 total greenhouse gas (GHG) emissions increased by 84% from 170 Tg/CO_2eq in 1990 to 312.8 Tg/CO_2eq in 2005 (Table 6), in line with GDP growth [31]. The energy sector accounted for 77.3% of the total in 2006. The other contributing sectors are the waste sector (9.5%), industrial processes (8.1%) and agriculture (5.1%) [82]. On the other hand, CO_2 emissions account for 82.1% and CH_4 emissions for 15.8% of total GHG emissions. Most (92%) of total CO_2 emissions are from fossil fuel combustion [81,82].

6. Clean and sustainable energy policy

The basic principle of Turkish energy policy, as set out in the 9th National Development Plan (2007–2013), was to ensure sufficient

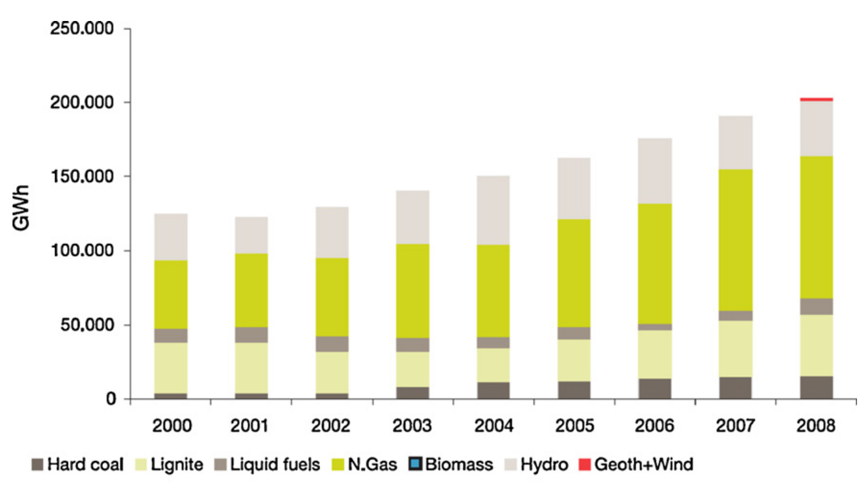

Fig. 5. Electricity consumption by source in Turkey.

energy supply to meet the increasing demand, at the lowest cost possible. The 9th plan also introduced provisions for minimising negative environmental impacts, improving energy efficiency and increasing the share of renewable energy in energy consumption [36].

6.1. Reducing pollution from energy production

The government further reformed the regulatory framework to reduce pollution from energy production. In 2006, the new Regulation on Control of Air Pollution from Industrial Plants set standards for emissions of NOx, SO_2, CO and PM from combustion plants. PM and CO standards were lowered for both solid and liquid fuel-fired power plants [81]. Some investments have already been made, especially to address the environmental impacts of the high sulphur content of domestic lignite. New lignitefired power plants have been equipped with flue gas desulphurisation (FGD) technology to comply with regulations. Six of eleven pre-1986 lignite-fired plants have been retrofitted with electrostatic precipitators (ESP) to reduce particulate emissions. However, not all electrostatic precipitators are working at maximum efficiency. Construction of one power plant based on circulating fluidised bed technology has recently been completed. This first application of advanced coal technology in Turkey, designed to use low-quality lignite with high sulphur content, was followed by other plants [36,80–82].

6.2. Improving energy efficiency

Energy intensity decreased by 8% between 1990 and 2006 and is below the OECD average. Its improvement through improved sectoral energy efficiencies is an important objective of Turkey, which should bring multiple benefits: economic benefits, environmental benefits and related health benefits. Official studies have demonstrated that Turkey has large energy conservation potential (25–30%). Energy efficiency policies have been implemented in the industrial, residential and services sectors. General investment support programmes also have an indirect positive impact on energy efficiency. There are no direct tax incentives to encourage end-use energy efficiency, nor is there any other kind of direct financial incentives. The National Energy Conservation Centre (EIE/NECC) has provided training to consumers on energy conservation measures, conducted energy audits in industry, maintained energy consumption statistics for the industrial sector and public buildings, and co-ordinated dialogue and co-operation with the relevant institutions [32,34,82].

6.3. Promoting renewable energy

In Turkey, renewables represent about 36.3% of total primary energy production. More than half of the renewables used in Turkey are combustible fuels and waste, the rest being mainly hydro, solar and geothermal. Turkey is richly endowed with hydropower, wind and geothermal resources. Sectoral studies have indicated that small-scale is underdeveloped, with 130 plants in operation compared with 350 prospective development sites and a total potential production of 36 TW h of electricity per year. It is estimated that Turkey has the potential for up to 11,000 MW of wind power capacity (mostly along the coasts), capable of generating about 45 TW h of electricity per year [15–17,57–60].

There is also large potential for geothermal and solar thermal applications in Turkey. Solar collectors are already a significant, market-driven business. The government expects the use of geothermal and solar energy to double between 2007 and 2020. The Geothermal Energy Law, enacted in 2007, aims to boost geothermal residential heating. The organic component of waste incineration is also considered a renewable option in the future, using appropriate technology to meet high health and environmental standards. On the other hand, commercial use of renewable energy has not developed rapidly. Financial assistance is being provided for the development of renewable energy projects. In 2007, USD 290 million was made available; by 2008, about half had already been committed to finance 24 projects with several other projects under preparation [33–35,68,69].

7. Conclusions

Energy is essential to life and human society cannot surviva without a continuous supply of energy. However, although energy has brought about significant changes in standards and life-styles, its generation, processing and consumption is also a source of both localized pollution and a major contributor to global climate change. In this context, at the international level, the challenges related to energy and climate change are at the very top of the agenda for action, and more than ever before, renewable energy is proving its potential as an important part of the solution. The rough their concrete contribution to clean and secure energy, renewables ensure that an increasing amount of energy is produced without using fossil fuels and without emitting greenhouse gases or harmful air pollutants. The warming of the global climate system as a result of increasing greenhouse gas (GHG) concentrations in the atmosphere has become a major concern worldwide. Climate change is manifest in higher average global temperatures, rising global mean sea levels, melting ice caps and an increased intensity and frequency of extreme weather events. Therefore, the role of renewable energy sources for climate change mitigation is important. By using these energy sources as much as, the amounts of the greenhouse gas concentrations in our atmosphere will be diminishes.

Renewable energy supply in Turkey is dominated by hydropower and biomass, but environmental and scarcity-of-supply concerns have led to a decline in biomass use, mainly for residential heating. As a contributor of air pollution and deforestation, the share of biomass in the renewable energy share is expected to decrease with the expansion of other renewable energy sources such as solar and wind. Turkey has substantial renewable energy sources such as hydropower, solar, biomass and wind power. There is also significant potential for wind power development. Renewables exception of large hydro are widely dispersed compared with fossil fuels, which are concentrated at individual locations and require distribution. Hence, renewable energy must either be used in a distributed manner or concentrated to meet the higher energy demands of cities and industries.

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